♦ APPENDIX A. DEFINING THE OPPORTUNITIES AND CONSTRAINTS: A HISTORICAL PERSPECTIVE

THE IMPORTANCE OF A HISTORICAL PERSPECTIVE

The CALFED Ecosystem Restoration Program will succeed only to the extent that it is based on a solid understanding of natural physical and ecosystem processes and habitats, and how these have been changed, so that restoration actions can be effective, adequate, and realistic. To be most effective, restoration actions should restore processes that maintain conditions favorable to native species so that ecological benefits are sustainable and will not disappear in the next flood or from other impacts on artificially-created habitats. We must know the former extent of habitats and the former range of hydrologic and ecological processes to understand the habitat needs of important species, and to therefore judge the scale of restoration needed to bring about recovery and to establish healthy populations.

Many restoration actions have been very small-scale affairs when viewed in context with the losses in habitat and changes in processes since 1850. Although these projects may be very worthwhile, they should not be considered as having restored the ecosystem just because 10 acres of tidal marsh have been restored at a given site. Similarly, the irreversible changes that have occurred to hydrology and ecology of the Bay-Delta system must be recognized so that restoration goals are realistic. For example, the hydrology of the Bay-Delta system has been fundamentally transformed by massive reservoirs and diversions. Reservoir storage capacity in the Sacramento-San Joaquin River system now totals about 30 million acre-feet (MAF), with storage equivalent to over 80% of runoff in the Sacramento River Basin and nearly 140% of San Joaquin River Basin runoff (San Francisco Estuary Project 1992, Bay Institute 1998). As a result, frequent floods (important for maintaining channel form, cleaning spawning gravels, and providing periodic disturbances needed to maintain native species) have been eliminated or drastically reduced on many rivers. Most of these reservoirs are permanent, at least for the lifetimes of the structures, so restoration efforts must be designed to account for the changes wrought by the dams or must involve changes in the operation of the reservoirs. Although dam removal may be possible (with considerable ecological benefits) in a limited number of cases, as is now being considered for Englebright Dam on the Yuba River, in most cases restoration actions must be designed with the reservoirs in mind.

CONDITIONS BEFORE EUROPEAN COLONIZATION

The landscape of the Central Valley has changed on such a vast scale in the past 150 years that it is difficult to even imagine what it was originally like (see Kahrl et al. 1978, Kelley 1989, Bay Institute 1998). Arguably, the most important ecological features were the aquatic and riparian ecosystems, which covered huge areas, supported high concentrations of fish and wildlife, gave rise to many endemic species, and were the cultural focus of the Native American peoples. Before European colonization, the Sacramento and San Joaquin rivers and their tributaries carried water, sediment, nutrients, other dissolved and suspended constituents, wood, organisms, and other debris from basins (of more than 25,000 and 14,000 square miles, respectively) to their confluence in an inland delta, thence through Suisun, San Pablo, and San Francisco Bays to the Pacific Ocean. The channels of these rivers served as habitats and migration routes for fish and other organisms, notably several distinct runs of chinook salmon (*Oncorhynchus tshawytscha*), steelhead trout (*O. mykiss*), and Pacific lamprey (*Lampetra tridentata*). These species evolved to take advantage of the hydrologic and geomorphic characteristics of these river systems, some of which are discussed below. There are no firm data on pre-1850 salmon runs, but anecdotal accounts (and the large canning industry that later developed in coastal and inland cities) imply that runs were substantial, probably between 2 and 3 million per year.

The Mediterranean climate ensured that the aquatic and riparian systems were highly dynamic, driven by strong annual patterns of wet and dry seasons and longer periods of extreme drought and extreme wet. The high peaks of the Sierra Nevada intercepted much of the moisture coming off the ocean and stored it as snow and ice, which melted gradually, generating cold rivers that flowed throughout the dry summers. During periods of high snowfall and rainfall, the Central Valley would become a huge shallow lake, taking months to drain through the narrows of the Bay-Delta system. In periods of drought, the main rivers would be reduced to shallow, meandering channels, and salty water would push its way to the upstream limits of the Delta. The dry tule marshes would burn, perhaps with fires deliberately set by the native peoples, and the dry air would be filled with smoke for months at a time.

The marshes were a major feature of the lowlands of the Central Valley, especially the San Joaquin Valley, where they surrounded the huge, shallow lakes at the southern end of the valley, Lakes Buena Vista and Tulare. The Delta itself was a vast marshland, the present-day islands vaguely defined by natural levees of slightly higher ground. The river channels meandered through this marsh, making trips by boat long and arduous. Suisun, San Pablo, and San Francisco Bays were also lined with large marshes that penetrated far inland in the estuaries of in-flowing streams and in the shallows now called Suisun Marsh. The flood basins of the Sacramento River also supported extensive marshes. Upstream, the river channels were defined by thick riparian forests, with dense stands of willow, cottonwood, and sycamore close to the water, yielding to valley oak on the higher terraces. Above these woodlands were first oak savannas and then bunch grass prairies, supporting herds of pronghorn, elk, and blacktail deer.

HYDROLOGY AND LANDFORMS AND HOW THEY INTERACT TO FORM HABITAT

RUNOFF PROCESSES AND RIVERINE FORMS

The largest rivers of the Sacramento-San Joaquin River system begin in the high elevations of the Sierra Nevada (or Cascades) and receive runoff from snowmelt, which is at a maximum in late spring/early summer, as well as rainfall in their lower elevations, with maximum flows (typically with higher peaks) in winter during storms. The highest peak flows are produced when warm rains fall on a large snowpack, such as occurred in December-January 1997. There is considerable variation in precipitation (and therefore riverflows) from year to year, but snowmelt reliably produced moderately high flows in most years. The seasonal low flows typically occurred in late summer and fall, after snowmelt had been exhausted and before the onset of winter rains. Seasonal flow variability was greatest in rainfall-dominated rivers draining the Coast Ranges, somewhat less in rivers with snowmelt contributions, and substantially less in rivers draining volcanic formations, such as the regions of Mt. Shasta and Mt. Lassen (where runoff is dominated by springflow). In the Delta, inflows from the Sacramento and San Joaquin rivers mixed, with probable intrusions of salt water during dry periods, in a complex, often stratified pattern.

The upper reaches of the rivers are typically bedrock or boulder controlled, with cascade and step pool habitats, and with little opportunity for sediment storage. In their lower reaches, the rivers flow through the alluvial Central Valley in braided, wandering, or meandering channels, historically with broad, largely forested, floodplains. Braided channels were common where streams passed from bedrock-controlled channels onto the flatter Sacramento Valley floor, depositing gravel and sand. Flatter floodplain reaches were characterized by large, meandering channels, which frequently overflowed onto the adjacent floodplains, depositing sandy natural levees along the channel, with silty (and fertile) overbank sediments behind.

In the Delta, a complex of low-gradient, multiple channels was flanked by natural levees and low-elevation, frequently inundated islands (composed largely of organic-rich sediments). The tidal estuaries of Suisun, San Pablo, and San Francisco Bays were flanked by extensive tidal marshes and mudflats.

Each of these geomorphic features, interacting with a variable flow regime, created a distinct suite of aquatic or riparian habitats, as illustrated by an actively migrating meander bend (Figure A-1). As flow passes through a meander bend, the highest velocities and greatest depths are concentrated near the outside bank, which erodes, producing a steep cut bank, commonly with overhanging vegetation. These pools are important holding habitats for adult salmon and trout. In between the meander bend pools, where flow crosses over from one side of the channel to the other, a riffle typically occurs, with shallow flow over gravel or cobble substrate, providing habitat for invertebrates (which are food for fish). Gravel riffles provide spawning habitat for salmon and trout. Shallow margins of these channels, protected areas behind exposed roots and large woody debris, and the interstices between large cobbles, provide habitat for juvenile salmon.

Native Species and How They Used the Landscape

The productive marshlands and intervening waterways were extremely attractive to waterfowl. The abundant and diverse resident populations of ducks, geese, shorebirds, herons, and other birds were augmented by millions of ducks, geese, shorebirds, and cranes migrating down in fall and winter from summer breeding grounds in the north. The migratory birds would take advantage of the expanded wetlands that were the result of the winter rains and floods. Arguably, the Pacific Flyway, one of the major migratory routes for birds recognized for North America, owes its existence to the Central Valley and its wetlands. No matter how severe the drought, there would be wetlands somewhere in the valley.

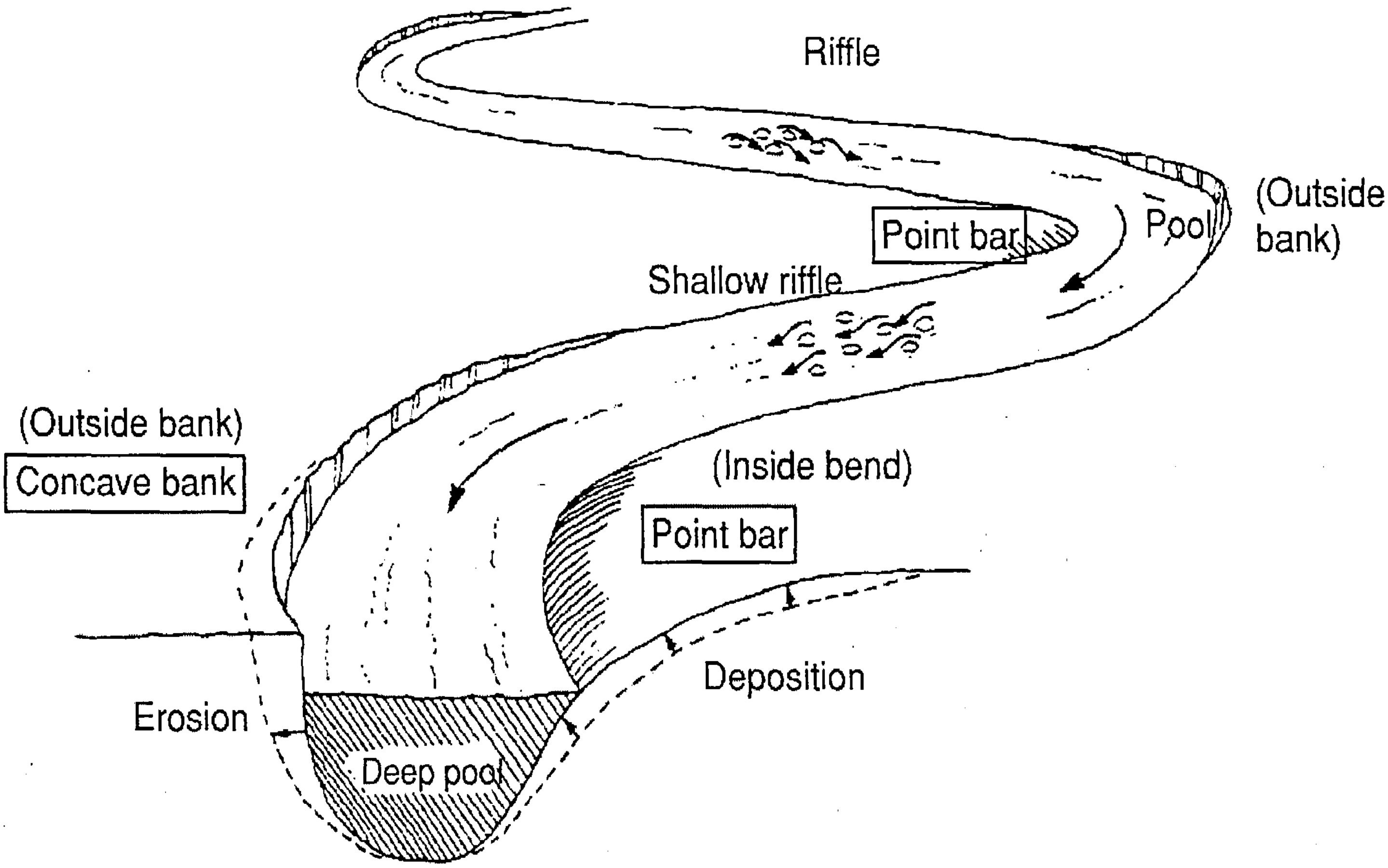
Migratory fishes also found the region to be very favorable habitat. Two to three million anadromous chinook salmon spawned in the system each year, along with large numbers of steelhead, sturgeon, and lamprey. The four distinct runs of salmon reflect a fine-tuning of this species to a fluctuating yet productive environment. Fall-run chinook were the lowland run. They came up in fall months as soon as water temperatures were cool and spawned in low-elevation rivers in time to allow their young to emerge from the gravel and leave the rivers before conditions became unfavorable in early summer. Spring-run chinook, perhaps the largest of the runs, beat the summer low flows and high temperatures by migrating far upstream in the spring and holding in deep cold pools through summer, to spawn in fall. Late-fall-run and winter-run chinook took advantage of the unusual conditions in the little Sacramento, McCloud, and Pit Rivers, where cold glacial-melt water flowed from huge springs, keeping temperatures cool even in the hottest summers, so the fish could spawn late in the season.

Steelhead migrated up in winter, when flows were high, even higher in the watersheds than spring-run chinook, and sought out smaller streams not used by salmon.

The annual influx of millions of salmon weighing 8-20 kilograms each represented a tremendous shot of oceanic nutrients injected into the stream systems, enhancing the productivity of the aquatic and riparian ecosystems and increasing their ability to support juvenile salmon and steelhead. The juveniles of all these salmon would move downstream gradually in winter and spring, taking advantage of the abundant invertebrates in flooded marshlands and the shallow waters of the Delta. In this environment, they could grow rapidly on diets of insects and shrimp, reaching sizes large enough to enhance ocean survival.

In the estuary, the abundant longfin and delta smelts could also move up and down with seasons, seeking favorable conditions for spawning and rearing of young. The short (1 to 2-year) life cycles of these fish testifies that no matter how dry or wet the year, the appropriate conditions were present somewhere in the system. The resident fishes, in contrast, were largely stream or floodplain spawners and apparently did not necessarily find appropriate conditions for spawning and rearing of young to be available every year. As a consequence, they adopted the basic life history strategy of living long enough (5 or more years) to be around when favorable conditions were present and to flood the environment with large numbers of young. Middens near Native American village sites indicate that these fishes (e.g., thicktail chub, Sacramento perch, splittail, hitch, and Sacramento blackfish) were extremely abundant and easy to harvest.

The abundance of fish in the middens also indicates that the native peoples were major predators on the



Source: California State Lands Commission 1993.

Figure A-1: Diagram of Meander Bend, Showing Variety of Forms (and thus Habitats) Associated with Actively Migrating Meander Bend.

fish, including salmon. The abundance of fish was presumably one of the reasons why these people were able to exist in relatively high densities (compared to other areas of North America). Although they may have depleted some of the resources they used (Broughton 1994), some abundant fishes were lightly used if at all. For example, the principal salmon run harvested was the fall run, both because of its accessibility and because the fish were less oily than fish of other runs, making them easier to dry for long-term storage. Other salmon runs were harvested less intensively and steelhead hardly at all.

The native species in this productive ecosystem were adapted to hydrologic extremes, with specific salmon runs adapted to take advantage of different parts of the annual hydrograph. A range of species and life stages used different habitats in different parts of the system.

CRITICAL ASPECTS OF LANDSCAPE AND ECOLOGICAL FUNCTIONS

From our knowledge of the functioning of the natural system, we can identify critical aspects that would need to be addressed in a successful restoration program.

Habitat Area and Diversity. Minimum habitat areas are needed to maintain viable populations of native species. This habitat also has to contain the complex features needed to maintain multiple species and multiple life stages of each species. For example, high-quality brackish and freshwater tideland (including shallow-water habitats, such as mudflats, tule marsh, small sinuous sloughs and distributaries, upper tidal marsh types [e.g. pickleweed], and riparian scrub) historically occurred along the Sacramento and San Joaquin River channels, in the west Delta and Yolo Basin (north Delta), and in the North Bay tidelands of Napa and Sonoma Valleys. Also historically, the salinity gradient of the estuary varied greatly seasonally and between water years, but because these habitats were well distributed along the estuarine system, there were always large expanses of shallow-water habitat associated with the saline/freshwater mixing zone (hydrologically connected). Today, these habitats occur primarily in Suisun Bay, Suisun Marsh, and lower Sherman Island. In all, the area of tidal marsh and active floodplain habitat has been reduced to probably less than 5% of its pre-1850 extent. Such massive reductions in habitat imply a substantial change in the ability of the species dependent on those habitats to sustain their population levels.

PHYSICAL AND ECOLOGICAL PROCESSES. The habitats of the pristine Bay-Delta system can be viewed as forms that developed and were maintained by processes such as flooding, sediment transport, establishment and scour of vegetation, channel migration, large woody debris transport, groundwater seepage, tidal circulation, and sedimentation. For these habitats to be sustainable in the long term, restoration of processes will be more effective than physical creation of forms no longer maintained by processes. Floodplain inundation and forest succession are two such processes along alluvial rivers.

Floodplain forests depended on periodic inundation of the floodplain to maintain appropriate moisture and disturbance regimes, which also discouraged invasion by upland species. Along many rivers, the floodplain is now leveed, and upstream dams have reduced the frequency of high flows. Thus, restoration of floodplain forests will require more than grading floodplain surfaces and planting suitable trees. Levees may need to be removed, breached, or set back, and the river will need periodic high flows capable of inundating the floodplains.

As alluvial river channels migrated across the valley bottoms (through erosion and deposition), they created new (sandy) surfaces on which pioneer riparian species (willow and cottonwood) could establish. Over time, silty overbank sediments deposited and built up the site, and later successional stage trees, such as sycamore, ash, and eventually valley oak, would establish and mature. Thus, the channel migration and its attendant erosion, deposition, and ecological succession were important processes in maintaining habitat diversity along alluvial rivers.

DELTA HYDRAULICS AND ECOLOGICAL FUNCTIONS. Bay-Delta channels were characterized by channel hydraulics that on a temporal, tidal, and seasonal basis for a given hydrologic condition supported important ecological functions such as sustaining a productive food web, providing spawning, rearing, and feeding habitat for estuarine and anadromous fish, and supporting migration of adult and juvenile fish. Reduced Delta inflow, exports from the Delta, and conversion of tidal wetlands have had a large influence on the natural hydraulic regime of the Bay-Delta. Actions such as modified water project management and flood plain and tidal wetlands restoration can contribute to restoring or a more natural hydraulic regime that sustains ecological functions and meets the life requirements of the fish and wildlife in or dependent on the Bay-Delta.

TEMPORAL VARIABILITY. The rivers of the Sacramento-San Joaquin system were dynamic environments, with temporal variations from seasonal and interannual variations in flow and sediment load, often resulting in changes to the channels themselves during floods. Such temporal variability is recognized to be important ecologically, with the periodic disturbances of floods playing an important role in maintaining riverine ecological communities (Resh et al. 1988, Wootten et al. 1996) and their habitats. Periodic droughts may also have been important, with upstream migration of salt water into Delta channels likely. This implies that seasonal and interannual variability, especially high flows, is important for restoration of the ecosystem.

In the Bay and Delta, the intrinsic value of brackish and freshwater tidelands is well documented, including high primary and secondary productivity, fish rearing and foraging habitat, and habitat for a high diversity of native animals and plants, including many at-risk species (general avian and semi-aquatic mammal [e.g., otter] habitats). Less understood are the functional relationships and interdependencies of open water (pelagic) habitats and species of the Delta to these formerly more common peripheral, shallow water habitats. Moreover, these habitats were subjected to a temporally variable salinity gradient (seasonally and year to year), with saline water intruding far upstream into the Delta during periods of low flow (especially droughts) and fresh water extending far downstream into San Francisco Bay during floods. This dynamic, temporal variability presumably favored native species, and the current reduction of such variability may have facilitated establishment of non-native species.

SPATIAL VARIABILITY. The river channels were also characterized by spatial variability (or complexity), arising from irregularities in channel form, both transverse to and longitudinal with the flow direction. For example, in meander bends the channel is typically deeper on the outside of the bend, increasingly shallow toward the inside bank onto a point bar. This variation in water depth is accompanied by variations in grain size of bed sediment and in water velocity. Longitudinally, irregularities include large-scale alternations between bedrock to alluvial reaches, steep (riffle) and low-gradient (pool) reaches, transitions between reaches of differing widths, passage over and around channel bars, and effects of boulders and large woody debris in the channel. The riverbanks were typically irregular in outline and often were made more irregular by protruding trees (living and dead). Such spatial irregularities were ecologically important because they created a diversity of habitats, which in turn supported a diversity of species and life stages of those species. The importance of complexity in physical habitat implies that in many artificially straightened or deepened channels, it may be advantageous to physically restructure the channel or to add elements likely to induce scour or deposition or both.

CONTINUITY. The longitudinal continuity of water flow, sediment transport, nutrient transport, and transport and migration of biota through the river system, as well as the longitudinal continuity of riparian and aquatic habitat along the length of a river, were important attributes of the ecosystem. The transport of gravel from mountainous source areas provided spawning habitat in alluvial channels downstream, and the continuity of channels allowed for upstream migration of spawning salmon, waterborne dispersal of seeds, and invertebrate colonization. Similarly, the longitudinal continuity of riparian vegetation flanking the stream was an important attribute of the riparian habitat for wildlife, as well as for shading the channel and providing carbon to the aquatic system. The importance of continuity implies that conservation and restoration projects should be prioritized, in part, to maximize continuity of habitat, so that sites whose restoration would connect different habitats would have priority over other, similar sites.